The Conference of Basic Science and Applications
Science Faculty

Utilizing Thermodynamic Parameters and Isotherms to Study the Adsorption of Oak Galls Extract Inhibitor on the Cast Iron Surface in Atmospheric Environment

Mohammed Al-Madani[a]*, Saleh Qnified[b], Taha Ebrahim[c], Yussri Salem[d]

a and c Material & Corrosion Engineering Department, Faculty of Engineering, Sebha University, Sebha, Libya.
b Mining Department, Faculty of Natural Resources, Al-Jufra Uiversity, Soukana, Al-Joufra, Libya.
c Conservation Department, Faculty of Archaeolog , South Valley University, Qena 83523, Egypt.

Keywords:
High Carbon Steel
Atmospheric Corrosion
Oak Galls Extract
Adsorption Isotherm Models
Inhibitor Surface coverage

ABSTRACT

A previous study employed the weight loss approach of the treated coupons after exposure to 85% relative humidity in a humidity chamber to assess the effects of Oak Galls Extract (OGE) as a green corrosion inhibitor of cast iron (iron artifacts) in the atmospheric environment. The morphology of an adsorbed inhibitor on the surface was also studied using optical and scanning electron microscopy. By changing the inhibitor concentrations (2%, 4%, and 6% by weight of the solution), the inhibitory effect was taken into account. The results of the measurements showed that OGE had a high degree of inhibition, with an approximate 95% efficiency at 6% concentration. OGE was suggested as an effective green inhibitor for cast iron (iron artefacts) based on the findings of that investigation. The adsorption of a (OGE) inhibitor on the surface of cast iron was investigated in the current work. The adsorption experiment made use of a number of adsorption isotherms, including Langmuir, Temkin, Freundlich, Adejo Ekwenchi, and El-Awady. The (OGE) inhibitor not obeying with most of the used isotherm models, with, indicating that the inhibitor has moderate to poor adsorption on the cast iron surfaces. On the other hand, (ΔG°_{ads}), revealed that the adsorption mechanism of inhibitor on the cast iron surface was physisorption.

أستخدام معاملات الديناميكية الحرارية والنماذج الايزوثيرم لدراسة إمتزاز مثبط مستحلب ثمار البلوط على سطح الحديد الزهر

محمد المدني[a] و صالح قنيفيد[b] و يسري سالم[c]

a قسم هندسة المواد والتآكل – كلية الهندسة – جامعة سبها – سبها – ليبيا
b قسم التعدين – كلية الموارد الطبيعية – جامعة الجفرة – الجفرة – سوكنة - ليبيا
c قسم الحفظ – كلية الأثار – جامعة جنوب الوادي – قنا – مصر

الكلمات المفتاحية:
الفولاذ العالي الكربون
تآكل الهواء الجوي
مستحلب ثمار البلوط
نماذج مقاييس الإمتزاز
التغطية السطحية للمثبط

الملـخـص:

وفقًا لدراسة سابقة تم أختبار مدى تأثير المثبط الكيميائي مستحلب ثمار البلوط الصديق للبيئة البولي على تآكل الحديد الزهر في الهواء الجوي بإستخدام طريقة فقدان الوزن. كما تم دراسة الشكل المرفولوجي لإمتزاز المثبط على سطح المعدن بإستخدام المجهر الإلكتروني البصري والمسح الضوئي. تم الأخذ في عين الإعتبار ثلاث تركيزات مختلفة من المثبط (2 و 4 و 6 % من وزن المحلول). أظهرت نتائج الدراسة السابقة أن المثبط المستخدم له درجة حماية عالية من التآكل تصل الى 95% عند تركيز 6%. وعليه تخلص النتائج الى أن مثبط مستحلب ثمار البلوط فعال في حماية أسطح الحديد الزهر من التآكل. في البحث الحالي تم دراسة مدى درجة أمتزاز المثبط على سطح المعدن باستخدام معامل الديناميكا الحرارية (طاقة الأمتزاز الحرة) وكذلك باستخدام النماذج الأيزوثرمية لقياس الأمتزاز, وتشمل كلاً من: لانجمويز وتيمكين وفروندليش وأديجو إكوينشي والعوادي. بينت قيم معامل الأرتباط لنماذج الأمتزاز تبين أن مستحلب ثمار البلوط المثبط لا يتوافق مع معظمها، وكان متوافقاً فقط مع نموذج لانجمويز. يخلص البحث الى أن درجة إمتزاز المثبط على سطح الحديد الزهر ضعيفة الى متوسطة, وآلية الإمتزاز كانت فيزيائية.

1. Introduction

With reference to *Yussri Salem*'s work from 2020 [1], which assessed the impact of *Oak Galls Extract* (OGE) as a green inhibitor on the corrosion behaviour of cast iron (iron artefacts) in an atmospheric setting. It was found that when these cast iron coupons were exposed to it, the weight loss and corrosion rates decreased along with the inhibitor concentration. The minimal corrosion rate was measured at 0.0002 $mg.cm^{-2}.hr^{-1}$, while the highest corrosion inhibition efficiency was found to be 95% when the inhibitor concentration was at its maximum, or 6%.

Cast iron has been crucial to the evolution of the human species. For thousands of years, they have been made in a

*Corresponding author: Mohammed Al- Kilani Al-Madani, Departent of Material & Corrosion Eng.- Sebha University-Sebha-Libya.
moh.ibrahim@sebhau.edu.ly

variety of compositions. To meet structural and shape requirements, they have often been employed in as-cast form [2]. Graphite (pure carbon), carbide (Fe3C), or solid solution in austenite (austempered ductile iron, or ADI) are the three forms of carbon that can be found in cast irons, which are alloys of iron, carbon, and silicon [3].

Due to their microstructure, component compounds (graphite and phosphate eutectic), and the robust compact surface created by cooling after casting, cast irons are resistant to uniform corrosion. However, historical structures have been subjected to hostile air settings for decades or centuries, and some of them have experienced corrosion attack [4]. Although the shape of the graphite and the quantity of large carbides are important for mechanical qualities, they have little impact on cast irons' corrosion resistance. Rarely, graphite can interact with the metal matrix cathodically, which could hasten the corrosion assault. The corrosion that occurs more frequently on other metals and alloys also occurs on cast iron. Uniform or general attack, galvanic or two-metal corrosion, crevice corrosion, pitting corrosion, intergranular corrosion, selective leaching, erosion-corrosion, stress corrosion, corrosion fatigue, or fretting corrosion are a few examples of the types of cast iron corrosion [5]. In the same environment, cast irons often corrode at a slower rate than steels. Although the long-term corrosion losses of cast iron are only approximately 25% of those for mild and low alloyed steels, the long-term atmospheric corrosion of cast iron is consistent (in terms of the shape of the regression function) with the models seen for mild and low alloyed steels. This is explained by the fact that protective corrosion products are held by the graphitized layer more effectively than by the rust that forms on mild steel [6].

This study looked into how oak galls adhere to the surface of cast iron (iron artefacts) to act as an ecologically benign corrosion inhibitor. Numerous investigations were carried out recently to assess the effectiveness of some plant and herbal extracts as inhibitors. These investigations demonstrated that certain plant and herb extracts can effectively prevent metal corrosion in a variety of conditions [7]. Due to consensus among chemists, archaeologists, and herbalists about the effectiveness of natural substances containing tannin as main chemicals in preventing corrosion, oak galls were proposed to be evaluated as a corrosion inhibitor of cast iron (iron artefacts) in the study which conducted by *Yussri Salem* [1]. Tannic acid, the primary component of oak galls, has also been found to act as a corrosion inhibitor for mild steel [8], in addition to this information. Therefore, oak galls are anticipated to have good qualities that hinder the corrosion of iron and its alloys, and they are likely to produce positive outcomes.

It could be able to utilize corrosion inhibitors to reduce how quickly ancient iron corrodes. Cathodic inhibitors slow the cathodic reaction (such as oxygen reduction) while anodic inhibitors slow the anodic process (such as iron corrosion). An inhibitor must get to the area where the cathodic or anodic processes take place in order to be effective. As a result, cathodic inhibitors must reach the electronic conductors in contact with the corroding iron (such as graphite on cast iron or conducting corrosion products like magnetite) and anodic inhibitors must reach the metal surface [9]. To stop or slow down corrosion, inhibitors are usually chemically or physically adsorbed to the metal's surface. How successfully an inhibitor inhibits corrosion depends on its capacity to bind to a metal's surface [10]. Despite the fact that some authors believe this phenomenon only represents the initial stage of the actual inhibition process, it is generally accepted that the inhibiting effect of organic compounds on the dissolution of metallic materials is caused by interactions by adsorption between the inhibitor and the metal surface [11]. Adsorption kinetics, adsorption heat, or the reversibility and specificity of the bond formed can all be used to identify the type of interaction taking place [11]. Electrostatic or van der Waals forces cause physically adsorbed species to interact quickly with the electrode, but they are easily washable off the surface, for example by dipping the metal into an inhibitor-free solution. Charge sharing or charge transfer occurs more slowly and with higher adsorption heat during the chemisorption process. This adsorption only affects a small number of metals and is only partially reversible [11, 12]. When the aforementioned characteristics are compared, it becomes

*Corresponding author: Mohammed Al- Kilani Al-Madani, Departent of Material & Corrosion Eng.- Sebha University-Sebha-Libya.
moh.ibrahim@sebhau.edu.ly

clear that chemisorptions, which can range from simple adsorption to the creation of genuine physical barriers, are frequently required for an effective inhibitory action. Many authors have proposed a wide range of general theories for the operation of inhibitors, including an increase in the proton discharge process's overvoltage, which forms the partial cathodic reaction of the corrosion process, an increase in ohmic resistance because an inhibitor film is present at the metal-solution interface, or nonspecific adsorption phenomena. [11 - 14]. Our understanding of the phenomenon has been greatly enhanced by in-depth analyses of the electrochemical behaviour of metallic materials in the presence of inhibitors, a thorough assessment of the potential dependence of the adsorption phenomena, and a better understanding of the energy parameters involved in the interaction between inhibitors and metallic materials [11].

2. Results of Weight loss, Corrosion Rate and Inhibitor Efficiency Related to Reference [1].

According to the research in Ref. [1], Table (1) presents the findings of corrosion tests including weight loss, corrosion rate, inhibitor efficiency and inhibitor surface coverage conducted on cast iron coupons in atmospheric environment (Environmental Chamber Test). Several adsorption isotherm models have been used to study the inhibitor's adsorption on the surface of carbon steel using these data.

3. Thermodynamic Parameters of Adsorption of *Oak Galls Extract* in Atmospheric Medium

In order to characterise the interaction between adsorbed molecules and metal surfaces, the free energy of adsorption, (ΔG°_{ads}), was determined using the formula:

$$\Delta G^{\circ}_{ads} = - RT \ln (55.5 \times K_{ads}) \qquad (1)$$

Where (K_{ads}) is the adsorption equilibrium constant, (R) is the gas constant (8.314 J. K^{-1}. mol^{-1}), (T) is the absolute temperature in Kelvin and the value of (55.5) is the concentration of water in solution expressed in (mol. L^{-1}) [15]. The free energy of adsorption is related to the equilibrium constant (K_{ads}) of adsorption, which can be calculated using the equation:

$$K_{ads} = (\frac{\theta}{1-\theta}) / I_{inh} \qquad (2)$$

Thermodynamic parameter including: adsorption constant (K_{ads}) and adsorption free energy (ΔG°_{ads}) of the *Oak Galls Extract* (OGE) in atmospheric medium is given in Table (2). The stability of the absorbed layer on the electrode surface is ensured by the negative value of (ΔG°_{ads}). In general, the values of (ΔG°_{ads}) up to (-20 KJ. mol^{-1}) are constant with the electrostatic interaction between the charged molecules and charged metal (physisorption), whereas the negative values higher than (-40 KJ. mol^{-1}) involve sharing or transfer of electrons from the inhibitors to the metal surface to form a co-ordinate type of bond [16].

Table (1) Weight Loss, Corrosion Rate, Inhibitor Efficiency and Surface Coverage Related to Ref. [1].

Sample No.	Inhibitor (Conce-ntration) I_{inh} (%)	Weight Loss (g)	Corrosion Rate ($mg.cm^{-2}.hr^{-1}$)	Inhibitor Efficiency (IE) (%)	Surface Coverage (θ)
1	Blank	1.210	0.0040	-	-
2	2.0	0.120	0.0004	90	0.90
3	4.0	0.060	0.0002	95	0.95
4	6.0	0.050	0.0002	95	0.95

Table (2) (K_{ads}) and (ΔG°_{ads}) of the *Oak Galls Extract* (OGE) in Atmospheric Environment.

Sample No.	Inhibitor (Conce-ntration) I_{inh} ($Mx10^{-3}$)	$\frac{\theta}{1-\theta}$	Adsorption Constant $(K_{ads}) = (\frac{\theta}{1-\theta})/I_{inh}$ (M^{-1})	Adsorption Energy (ΔG°_{ads}) (KJ. mol^{-1})
1	Blank	-	-	-
2	03.3898	09.00	2655.026	- 29.50
3	06.7797	19.00	2802.484	- 29.63
4	10.0102	19.00	1898.064	- 28.67

Based on the experimental information in Table (2), it was determined that the calculated value of (ΔG°_{ads}) was negative and less than (-40 KJ. mol^{-1}). Phyto-constituents are adsorbed on the metal surface by a powerful physical adsorption process, as shown by the values of (ΔG°_{ads}) for (OGE) extract, which range from (-29.63 KJ. mol^{-1}) to (-28.67 KJ. mol^{-1}). The strong and spontaneous adsorption of the (OGE) components on the metal surface is demonstrated by the relatively high and negative free energy value, which explains its high corrosion index. Thus, the proposed mechanism for the (OGE) inhibitor system is

*Corresponding author: Mohammed Al- Kilani Al-Madani, Departent of Material & Corrosion Eng.- Sebha University-Sebha-Libya.
moh.ibrahim@sebhau.edu.ly

most likely based on physical adsorption. In general, the presence of hetero atoms in the inhibitor molecules, such as N/O/S atoms with a single electron, may enhance the adsorption by causing the inhibitor molecules to become electrostatically adsorbed on the metal surface, producing insoluble stable coatings and lowering metal dissolution [17].

4. Adsorption Isotherm Models

4.1. Introduction

It is well known that the structural characteristics of the inhibitors affect how efficiently they bind to surfaces, and it is presumed that this adsorption is directly linked to the electrochemical reaction occurring on the metal surface [18, 19]. The adsorption of the inhibitor molecules from aqueous solution can be viewed as a quasi-substitution process between the water molecules at the electrode surface $H_2O_{(sol)}$ and the organic compound in the aqueous phase, $Org_{(aq)}$. In this case, $Org_{(sol)} + xH_2O_{(aq)} = Org_{(aq)} \cdot H_2O_{(sol)}$ the quantity of water molecules in inhibitor [19].

The outcomes of the experiment can be utilised to calculate the surface inhibitor's interaction. The kind, quantity, charge density, molecule size, interactions between the inhibitor and the metal, and formation of metallic complexes are all factors that influence how effective the inhibition is. The size, interactions between the metal and the inhibitor, and the production of metallic complexes are all factors that impact how effective the inhibition is, and adsorption isotherms provide this information. Adsorption isotherms provide details on the interactions between metal inhibitors [19]. The most often utilised adsorption isotherms for figuring out the mechanism of organo-electrochemical reactions are those of Lungmir, Temkin, Frumkin, Frendlich, Adejo Ekwenchi, and El-Awady. These are all general-type isotherms:

$$f(\theta, x) \exp(-2a\theta) = K_{ads} I_{inh} \qquad (3)$$

Where $f(\theta, x)$ is the configuration factor, which largely depends on the physical model and presumptions used to derive the isotherm, (θ) is the degree of surface coverage, (I_{inh}) is the concentration of the organic inhibitor in the electrolyte, (x) is the size ratio, which indicates how many molecules of water are displace by one organic inhibitor molecule, (a) is the molecular interaction parameter, and (K) is the equilibrium constant for adsorption. Corrosion is often assumed to be prevented by the development and maintenance of a protective coating on the metal surface [18]. In order to calculate the surface coverage, it was presumed that the adsorbed species' blocking effects account for the majority of the inhibitor efficiency, leading to the formula IE% = 100 x θ [19]. The values of the correlation coefficient (R^2) were used to select the isotherm that provided the best match after the surface coverage data were theoretically fitted into a variety of adsorption isotherms to gain insight into the inhibitor's adsorption process on the surface of cast iron [19].

4.2. Langmuir Adsorption Isotherm

The Langmuir isotherm, which describes gas-solid phase adsorption, is used to evaluate and compare the adsorptive capacity of different adsorbents [19]. The Langmuir isotherm expresses the relationship between a material's surface coating and inhibitor concentration as follows: [20]

$$\frac{I_{inh}}{\theta} = \frac{1}{K_{ads}} + I_{inh} \qquad (4)$$

Figure (1) illustrates a linear relationship between ($\log I_{inh}$) and ($\log (I_{inh}/\theta)$). Table (3) lists the Langmuir isotherm's parameters. The Langmuir adsorption isotherm is strongly adhered to, as indicated by the (R^2) value of 0.9995. There is no interaction between the adsorbate and adsorbent, according to the Langmuir isotherm application to the adsorption of *Oak Galls Extract* (OGE) inhibitor on the surface of cast iron [21].

Table (3) The Parameters of Isotherm Models for the *Oak Galls Extract* (OGE) Inhibitor on the Cast Iron Surface.

Sample No.	$\log I_{inh}$	$\log \theta$	$\log (\frac{\theta}{1-\theta})$	$\frac{I_{inh}}{\theta}$	$\log \frac{I_{inh}}{\theta}$
1	-	-	-	-	-
2	- 2.4698	- 0.04576	0.9542	0.0038	- 2.4237
3	- 2.1688	- 0.02228	1.2787	0.0071	- 2.1463
4	-1.9996	- 0.02228	1.2787	0.0105	- 1.9772

*Corresponding author: Mohammed Al- Kilani Al-Madani, Departent of Material & Corrosion Eng.- Sebha University-Sebha-Libya.
moh.ibrahim@sebhau.edu.ly

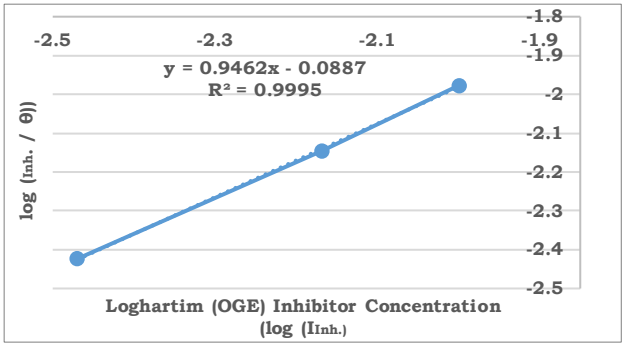

Figure (1) Langmuir Isotherm for Adsorption of *Oak Galls Extract* (OGE) Inhibitor on the Cast Iron Surface.

4.3. Temkin Adsorption Isotherm

The coefficient of surface coverage (θ) and inhibitor concentration (I_{inh}) of the Temkin adsorption isotherm are related by equation [22, 23, 24]:

$$\text{Exp.}\ (-2\ a\ \theta) = K_{ads}\ I_{inh} \qquad (5)$$

Plots of (θ) vs. log (I_{inh}) are displayed in Figure 2. The value of (R^2) is 0.8738. It may be said that the experimental data are not fits the Temkin adsorption isotherm well because (R^2) is lower than 0.9 and is far from unity [25, 26].

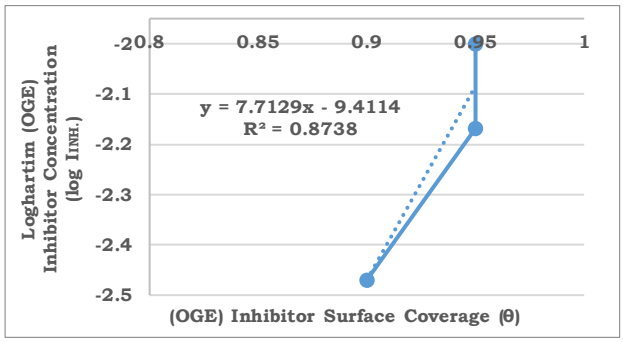

Figure (2) Temkin Isotherm for Adsorption of *Oak Galls Extract* (OGE) Inhibitor on the Cast Iron Surface.

4.4. Frendlich Adsorption Isotherm

The Frendlich adsorption isotherm model has been chosen as the final alternative for determining the adsorption potential of the absorbent solution. The formula results in the Frendlich isotherm [27]:

$$\log\theta + \log K_{ads} + n\log I_{inh} \qquad (6)$$

where n is the parameter for the interaction. Table (3) displays the Frendlich isotherm's parameters. The plot of log (θ) vs. log (I_{inh}) in Figure (3) also demonstrates a linear relationship and a (R^2) value of 0.8738, which is again lower that 0.9 and its far from unity, thus, the *Oak Galls Extract* (OGE) inhibitor is not obeying to Frendlich and Temkin models and cannot be considered as evidence that the adsorption of used inhibitor on a cast iron surface is suitable.

4.5. Adejo Ekwenchi Adsorption Isotherm

The Adejo Ekwenchi isotherm establishes an inverse relationship between the amount of adsorbate uptake from the bulk concentration and the difference between the total available surface on the adsorbent surface and the fraction that is covered by the adsorbate at that temperature [28]. This relationship holds true until the surface cover reaches its maximum value. According to the equation:

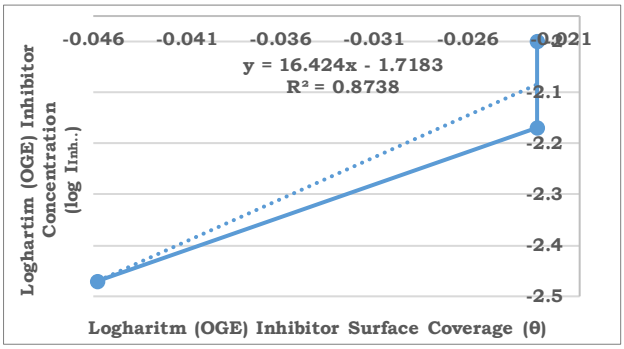

Figure (3) Frendlich Isotherm for Adsorption of *Oak Galls Extract* (OGE) Inhibitor on the Cast Iron Surface.

$$\log\ (1/1-\theta) = \log K_{ads} + b\ \log I_{inh} \qquad (7)$$

Where b parameter is used to determine the mode of adsorption of an inhibitor on the metal surface.

Table (4) The Parameters of Adejo Ekwenchi Isotherm Models for the *Oak Galls Extract* (OGE) Inhibitor on the Cast Iron Surface.

Sample No.	$\frac{1}{1-\theta}$	$\log(\frac{1}{1-\theta})$
1	-	-
2	- 1.00000	1.56438
3	- 0.05263	1.36438
4	- 0.05263	1.36438

*Corresponding author: Mohammed Al- Kilani Al-Madani, Departent of Material & Corrosion Eng.- Sebha University-Sebha-Libya.
moh.ibrahim@sebhau.edu.ly

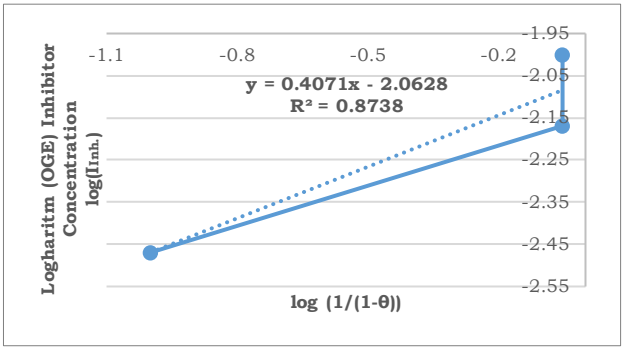

Figure (4) Adejo Ekwenchi Isotherm for Adsorption of *Oak Galls Extract* (OGE) inhibitor on the Cast Iron Surface.

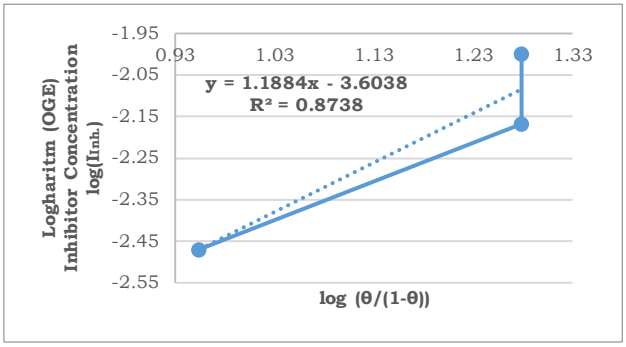

Figure (5) El-Awady Isotherm for Adsorption for the *Oak Galls Extract* (OGE) Inhibitor on the Cast Iron Surface.

Table (4) displays the Adejo Ekwenchi isotherm's parameters. Figure (4) shows a plot of log (1/1- θ) vs. log (I_{inh}) reveals a linear relationship with a (R^2) value of 0.8738, demonstrating that the isotherm for the adsorption of *Oak Galls Extract* (OGE) inhibitor on the surface of cast iron is not obeys the Adejo Ekwenchi isotherm model.

4.6. El-Awady Adsorption Isotherm

A fitting of the experimental data to the El-Awady isotherm model was performed. A feature of the model is represented by the equation [29]:

$$\log (\theta / 1- \theta) = \log K_{ads} + y \log I_{inh} \qquad (8)$$

Where y represents the number of active sites.

El-Awady isotherm's parameters are shown in Table (3). Figure (5) illustrates the linear relationship between log (θ /1- θ) and log (I_{inh}) reveals a linear relationship with a (R^2) value of 0.8738 and the El-Awady isotherm model is clearly not obeyed by the isotherm for the adsorption of *Oak Galls Extract* (OGE) inhibitor on the surface of cast iron. Generally, according to the values of correlation factors for the applied isotherm models, the only one model which is obeying to *Oak Galls Extract* (OGE) inhibitor is the Lungmir adsorption isotherm model with (R^2 = 0.9995). as shown on Figure (6). With no doubt it's clear that the adsorption of the inhibitor on the surface of cast iron (Iron artifices) is not limited.

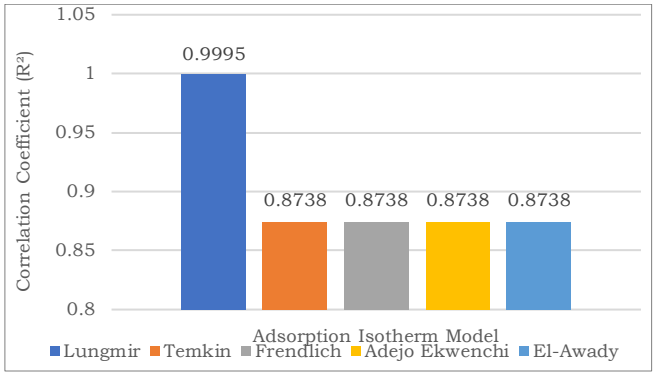

Figure (6) Comparison of Adsorption Isotherm Models.

5. Conclusions

Five adsorption isotherm models were used to investigate the adsorption behaviour of *Oak Galls Extract* (OGE) inhibitor on the surface of cast iron material. Based on the obtained results of the adsorption isotherm plots, the adsorption of *Eco-Friendly Polyester inhibitors* on cast iron in atmospheric environment obey to whole of the used isotherm models including Lungmuir, Temkin, Frendlich, Adejo Ekwenchi, and El-Awady, the obtained correlation factors (R^2) for these models were 0.9995, 0.8738, 0.8738, 0.8738 and 0.8738 respectively. The Lungmir isotherm model amongst the others gave the best fit since having the highest regression (R^2) value. *Eco-Friendly Polyester* inhibitor has been identified as it has a very excellent adsorption on the surface of cast iron. The mechanism of adsorption proposed for the *Eco-Friendly Polyester* inhibitor was physisorption since the values of ΔG°_{ads} are ranged in between (-29.63 to -28.67 kJ.mol^{-1}) and the negative and high values of ΔG°_{ads} indicated that there is a

*Corresponding author: Mohammed Al- Kilani Al-Madani, Departent of Material & Corrosion Eng.- Sebha University-Sebha-Libya.
moh.ibrahim@sebhau.edu.ly

strong and spontaneous adsorption of inhibitor on the cast iron metal surface. Thus, it can be concluded that *Eco-Friendly Polyester* inhibitor system was found to be in good agreement with the experimental results as a corrosion inhibitor to protect a surface of cast iron which has been approved by (*Yussri Salem*, 2022), and as it has a very excellent adsorption on the surface of cast iron metal as approved in the present paper research.

6. References

[1] Yussri Salem, Evaluation of Inhibition Efficiency of Oak Galls Extract as a Green Corrosion Inhibitor of Archaeological Iron Artifacts in the Atmospheric Environment, South Valley University, Conservation Department, Faculty of Archaeology, Qena 83523, Egypt, *Materials Research.; 23(5): e20200354*, DOI: https://doi.org/10.1590/1980-5373-MR-2020-0354, 2020.

[2] Davis, J.R., ASM Specialty Handbook: Cast Irons. Materials Park, OH: ASM International, 1996.

[3] Modern Casting Staff Report. Steady Growth in Global Output, Modern Casting. American Foundry Society, pp. 17–21, 2014.

[4] Miroslav Sykora, et. al., Corrosion of Historic Grey Cast Irons: Indicative Rates, Significance, and Protection, Czech Technical University in Prague, Klokner Institute, Prague, Czech Republic, Int. J. Comp. Meth. and Exp. Meas., Vol. 8, No. 2 (2020) 162–174.

[5] Melchers, R.E., Herron, C. & Emslie, R., Long term marine corrosion of cast iron bridge piers. Corrosion Engineering Science and Technology, 51(4), pp. 248–255, https://doi.org/10.1179/1743278215y.0000000049, 2016.

[6] Melchers, R.E., Long-term corrosion of cast irons and steel in marine and atmospheric environments. Corrosion Science, 68 pp. 186–194, https://doi.org/10.1016/j. corsci.2012.11.014, 2013.

[7] Zulkifli F, Nora'aini A, Sukeri M, Yusof M, Isa MIN, Nik WB. Henna leaves extract as a corrosion inhibitor in acrylic resin coating. Prog Org Coat, ;105:310-9. http://dx.doi. org/10.1016/j.porgcoat.2017.01.017., 2022.

[8] Hamilton DL. Methods of conserving archaeological material from underwater sites. Texas: Texas A&M University:1999.

[9] Turgoose, S., Corrosion inhibitors for conservation. In Keene, S. (ed.) Corrosion Inhibitors in Conservation, p. 13–17. (London: UKIC), 1985.

[10] Motsie Elija Mashuga, Adsorption, thermodynamic and quantum chemical studies of some ionic liquids as corrosion inhibitors for mild steel in HCl, B.Sc (Hons) (NWU), Department of Chemistry, Faculty of Agriculture, Science and Technology, North-West University (Mafikeng Campus), 111111 0600457310, July 2014.

[11] M. G. Fontana et. al., (eds.), Advances in Corrosion Science and Technology p. 174-175 © Plenum Press, New York, 1970.

[12] Suliman, M., Alkilani, M., Abdullah, T., & Ali, M., The Effect of MethyleCarbazodithoate" Corrosion inhibitor on Corrosion Behaviour of Low Carbon Steels in Acid Solution at Different Temperatures. Journal of Pure & Applied Sciences,18(4), 2019.

[13] Abhinay Thakur et. al., Anti-Corrosive Potential of the Sustainable Corrosion Inhibitors Based on Biomass Waste: A Review on Preceding and Perspective Research. Journal of Physics: Conference Series. 2267-012079, 2022.

[14] Alvarez P E, et. al. Rollinia occidentalis extract as green corrosion inhibitor for carbon steel in HCl solution, journal of Industrial and Engineering Chemistry, 58 92–9, 2018. [14] A. Bouyanzer and B. Hammouti, "A Study of Anticorrosion Effects of Artemisia Oil on Steel," *Pigment & Resin Technology*, Vol. 33, No. 5, 2004, pp. 287-292, Doi:10.1108/03699420410560489, 2004.

[15] R. Lindstrom, J.E. Svensson, L.G. Johnnsson, "The influence of salt deposits on the atmospheric corrosion of zinc", Journal of the Electrochemical Society, 149 (2), B57, 2002.

[16] P. Eriksson, L.G. Johansson, J. Gullam, "A laboratory study of corrosion reactions on statue bronze", Corrosion Science 34, 1083, 1993.

[17] El Azhar, M., Traisnel, M., Mernari, B., Gengembre, L., Bentiss, F., Lagrenee, M., Electrochemical and XPS studies of 2,5-bis(npyridyl)-1,3,4-thiadiazoles adsorption on mild steel in perchloric acid solution. Appl. Surf. Sci. 185, 197–205, 2002.

[18] Kahled K.F., *Electrochim Acta*. 48-2496, 2003.

[19] Li X., Deng S., Fu H., Corrosion Science 53-1529, 2011.

[20] T. M. Elmorsi, Equilibrium isotherms and kinetic studies of removal of methylene blue dye by adsorption onto miswak leaves as a natural adsorbent, ‖ Journal of Environmental Protection, 2(6), 817–827, 2011.

[21] S. Ach Arya and S. N. Upadhyay, "The Inhibition of Corrosion of Mild Steel by Some Flouroquinolones in Sodiumchloride Solution," Transactions of the Indian Institute of Metals, Vol. 57, No. 3, pp. 297-306, 2004. [20] I.B. Obot, N.O. Obi-Egbedi, and S.A. Umoren., Int. j. Electrochemical. Science, 4, 863-877, 2009.

[22] S. Bilgic and N. Caliskan, "An Investigation of Some Schiff Bases as Corrosion Inhibitors for Austenite Chromium-Nickel Steel in H2 SO4," Journal of Applied Electrochemistry, Vol. 31, No. 1, pp. 79-83. doi:10.1023/A:1004182329826, 2001.

[23] A. Bouyanzer and B. Hammouti, "A Study of Anticorrosion Effects of Artemisia Oil on Steel," Pigment & Resin Technology, Vol. 33, No. 5, 2004, pp. 287-292. doi:10.1108/03699420410560489, 2004.

[24] E. E. Ebenso, N. O. Eddy and A. O. Odiongenyi, "Inhibition of the Corrosion of Mild Steel by Methocarbamol," Portugaliae Electrochimica Acta, Vol. 27, No. 1, pp. 13-22. doi:10.4152/pea.200901013, 2009.

[25] S. A. Umoren, I. B. Obot, E. E. Ebenso., E-*Journal of Chemistry* 5(2), 355, 2008.

[26] A. A. El-Shafei, M. N. H. Moussa, A. A. El-Far., *Mater. Chem. Phys*. 70-175, 2001.

[27] Ebenso, E. E., N, O. Addy and Odiongenyi, A. O. Addy inhibitive properties and adsorption behaviour of ethanol extract of guinensis as a green corrosion inhibitor for mild steel in piper H_2SO_4. *African Journal of Pure and Applied Chemistry*, 11; 107-115, 2008.

[28] I. B. Obot, N.O. Obi-Egbedi, and S.A. Umoren., Int. j. Electrochemical. Scinece, 4, 863-877, 2009.

[29] Ali Fathima Sabirneeza Abdul Rahiman, Corrosion Inhibition, Adsorption and Thermodynamic Properties of Poly(Vinyl Alcohol-Cysteine) in Molar HCl, Department of Chemistry, Avinashilingam Institute for Home Science and Higher Education for Women, Coimbatore, Tamil Nadu 641043, India, Arabian Journal of Chemistry Volume 10, Supplement 2, May 2017, Pages S3358-S3366.

*Corresponding author: Mohammed Al- Kilani Al-Madani, Departent of Material & Corrosion Eng.- Sebha University-Sebha-Libya.
moh.ibrahim@sebhau.edu.ly